Alberta Oil Sands Environmental Research Program Review for the Fiscal Year 1984/85

AOSERP Report 134

Alberta
ENVIRONMENT

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ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM REVIEW FOR THE FISCAL YEAR 1984/85

AOSERP Report 134

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ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

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1987

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INTRODUCTION

Initiated in 1975, the Alberta Oil Sands Environmental Research Program (AOSERP) was designed to investigate the potential environmental effects of the intensive development planned for the Athabasca Oil Sands region in northeastern Alberta. In 1980, AOSERP was absorbed by the Research Management Division (RMD) of Alberta Environment. The program became one of a number of environmental research programs administered by the division, but has maintained the special status allotted to it prior to amalgamation. The AOSERP-funded research has endeavoured to find solutions for environmental problems arising from oil sands developments. Attention has also turned to the response of the ecosystem to various in-situ oil sands extraction and recovery processes which, because of their anticipated intense development, require effective environmental control standards. As a consequence, although research within the original AOSERP study area has been ongoing since 1980, the program has also become active in other oil sands and heavy oil areas in Alberta, most notably Cold Lake.

This report describes the major research activities of AOSERP during the 1984/85 fiscal year. The research conducted under the program reflects Alberta Environment's interest in incorporating knowledge about environmental problems into sound and informed policy decisions about the recovery of Alberta's oil sands reserves. The development of this vast energy resource is of great importance. However, such an endeavour must be guided by an understanding of how unavoidable disturbances to the natural environment affect the ecological balance and how potential damage can be mitigated. The Department's interest is in achieving a balance between efficient energy production and sound environmental management practices.

Through AOSERP, the Research Management Division funds, manages, and reviews scientific research aimed at determining applied solutions to environmental problems associated with development of energy resources. Because divisional personnel function in a flexible matrix management system, many areas of expertise can be brought together in the planning and designing of environmental research projects. Disciplines represented by the division include climatology, pedology, biology, ecology, sociology, and hydrology.

Staff members also act as a scientific resource for various government agencies and industries concerned with oil sands development.

Support for AOSERP research is provided by a camp and laboratory at Mildred Lake, located north of Fort McMurray. The Mildred Lake facility is designed as a base for environmental research within an area that is directly affected by oil sands development. It is used by both large and small consulting firms and private energy companies, as well as by a number of governmental and other agencies.

The following report is divided into three sections, each addressing a major research area in which projects were funded under AOSERP. These areas are:

1. The environmental effects of atmospheric emissions;
2. The environmental consequences of in situ extraction technologies; and
3. Land reclamation.

ENVIRONMENTAL EFFECTS OF ATMOSPHERIC EMISSIONS

The Acid Deposition Research Program was designed to plan and implement research specific to Alberta that would concisely address the following objectives:

1. To characterize sensitive environmental ecosystems and develop methodologies to identify and/or predict measurable short-, medium-, and long-term effects of acidic or acidifying substances on Alberta ecosystems;
2. To determine the characteristics and quantities of both long-range emissions and those generated locally, and to examine their effects on the environment;
3. To develop a basis and approach for preventive strategies and environmental protection; and
4. To co-ordinate departmental research on acid deposition with other private and public agencies in Alberta and the rest of Western Canada.

In 1984/85, a major activity of the Acid Deposition Research Program was the characterization and quantification of the ecological effects of acidic and acidifying substances in the Athabasca Oil Sands region. Considerable effort was expended on developing a more thorough understanding of the atmosphere-biosphere interface.

The emission of acid-forming substances into the atmosphere and their deposition and subsequent impact on the ecosystem are of significant concern. Because the magnitude and intensity of deposition are irregular and sporadic, the response of vegetation to pollution episodes is dependent upon the relationship and timing of the incident and the physiological development of the receptor. Specific projects have been geared to the accurate and frequent measurements of pollutant concentration occurrences and their interface with physiological, phenological, and productivity responses in vegetation species. Data generated will be used to develop a computerized numerical model for integrating chronic air pollutant exposures and tree growth response. A second major interface, between soil nutrients, microbiological processes, and vegetation, is also being studied.

Regional surveys to sample and chemically analyse event rainfall for total pollutant loadings in the Athabasca Oil Sands region were continued. Additional chemical analysis was undertaken to investigate probable causes of ion imbalances which had been quantified in the precipitation chemistry analysis. The historical data base of winter and summer precipitation chemistry data was evaluated and assessed for accuracy and reliability; and statistically analyzed for spatial and temporal variability. The suitability of the existing monitoring networks were also assessed. Wet deposition, however, is only one of two major mechanisms in the transfer of pollutants from source to receptor. Air pollutants released into the atmosphere are deposited continuously and cumulatively through both dry- and wetfall processes. Methodologies and instrumentation technology for measuring dry deposition were implemented in the field.

In conjunction with the aforementioned studies, research to determine the transport, dispersion, and transformation rates of oxides of sulphur and nitrogen emissions was continued. Such research is intended to facilitate the investigation of the medium- to long-range transport of acid-forming emissions from major emission sources in the area.

The Acid Deposition Research Program will provide scientific information for reviewing and evaluating Alberta's air quality standards, will assist in current and future planning of industrial development, and will enable a good understanding of the potential for environmental acidification. This program will establish a basis for sound, long-term environmental management. The data collected will be used in the development of methodologies that will identify and/or predict environmental deterioration caused by acid-forming emissions.

The planning and development of subsequent phases of the departmental Acid Deposition Research Program, managed by the Research Management Division, will be integrated and co-ordinated with the Alberta Government/Industry Acid Deposition Research Program (AGIADRP). AGIADRP is sponsored and managed on a fifty-fifty basis by government and industry, and has an estimated budget of $11 million dollars over the next six years.

PROJECTS

Air Quality Data Acquisition

The emission of acid-forming substances into the atmosphere and their deposition and subsequent impact on the ecosystem are of current concern. As the magnitude and intensity of deposition follows an episodic pattern, the response of vegetation to pollution is dependent upon the relationship and timing of the episode and the physiological development of the receptor. Therefore, air quality data must be interfaced with receptor response measurements.

To facilitate the implementation of an ecological monitoring research program, an air quality monitoring station was established in the vicinity of a permanent sample plot on the Sandalta lease in the Athabasca Oil Sands area. The station continously measures meteorological data and ambient concentrations of acid-forming gases. Data generated will be used to develop numerical models for interfacing air quality data to plant response measurements.

Annual reports are available from the Research Management Division..

Contractor: Western Research, Division of Bow Valley Resource Services Ltd.

Funding: $69 610.00

Chemistry of Summer Precipitation in the Athabasca Oil Sands Area

Atmospheric pollutants are scavenged from the air by rainfall. Since 1976, the Research Management Division has collected rainfall on an event basis in the Athabasca Oil Sands area. Analysis of the rain provides some indication of the amount and distribution of ion concentrations and insoluble/soluble metals present in the rainfall. Emissions from industrial sources in this region are under careful scrutiny. The concern is that these parameters will change in space and time as a result of additional sources of atmospheric emissions. The continued monitoring of precipitation chemistry will delineate any changes in the ionic characteristics and spatial

distribution of wetfall deposition resulting from the emission of pollutant from industrial sources in the area.

Contractor: CHEMEX Labs (Alberta) Ltd.
Mr. R. Olson

Funding: $44 250.00

Investigation of Ion Imbalance in Precipitation Chemistry Analyses

Although the problem of ion imbalances in precipitation samples has been recognized by various researchers, only a minimal effort has been made to quantify possible sources of the imbalance. This is of particular concern as ion imbalances have been quantified in summer precipitation samples collected in the oil sands region, and to a lesser degree in winter precipitation samples. The complete characterization of precipitation chemistry is essential to assess the potential acidification of the environment. The underlying causes of ion imbalances may relate to both physical and chemcial factors; however, this project will be directed towards examining only the effect of the following chemical factors on the ion imbalance:

1. The effect of analytical variability on each chemical element over the entire analytical range;
2. The quantification of other chemical species that may exist in the samples (e.g., organic acids and oxalates) and contribute significantly to the balance; and
3. The evaluation of techniques for measuring acidity and alkalinity.

Contractor: CHEMEX Labs (Alberta) Ltd.

Funding: $10 000.00

Evaluation, Analysis, and Assessment of Precipitation Chemistry Data in the Athabasca Oil Sands Region

Since 1976, the Research Management Division has undertaken projects to extensively sample and chemically analyze the accumulated snowpack and rain collected on an event basis in the AOSERP area. These projects have primarily entailed the collection and chemical analyses of the samples. Although

approximately five years of snowpack data and eight years of rain data have been collected, neither data set has been subjected to rigorous quality control, statistical analysis, and interpretation. The project would expedite the:

1. Quality control of the data to determine its accuracy and reliability; and
2. Statistical analysis of the data to document (a) the deposition patterns and spatial variability of wet deposition pollutant loading, particularly in relation to airmass trajectories, and (b) any trends in the concentration of ionic and particulate constituents of the precipitation.

Contractor: Concord Scientific Corporation
Funding: $55 000.00

Determination of Dispersion, Pollutant Trajectories, Precipitation Acidifying Processes, and Deposition Rates in the AOSERP Area - Phase III

Initiated in 1982 as a co-operative effort between the Alberta Research Council and the Research Management Division, the major thrust of Phase III will be to investigate the plume dispersion and transport of acid forming emissions to gain insight into the physics and chemistry of point source plumes. The chemical transformation and rate of removal of these emissions by both clouds and precipitation will also be investigated. The main objectives of the research are:

1. To determine the transport and dispersion of SO_2 and NO_x emitted in the AOSERP area;
2. To determine the transformation of SO_2, SO_4 and NO_x in the AOSERP area; and
3. To determine the redistribution and rate of removal of pollutants from the atmosphere by clouds and precipitation in the AOSERP area.

The airborne field measurements will provide baseline information for pollutant trend analysis and will be important for tracking pollutant/air mass trajectories from the emission sources.

Contractor: Atmospheric Sciences Department, Alberta Research Council
Funding: $55 000.00

Dry Deposition of Acid-Forming Emissions in Alberta

The measurement of the deposition of acid-forming emissions relies on both wet- and dryfall accumulation. In Alberta, dry deposition is considered to be as important as wet deposition; however, dry deposition rates are not well documented. This project, currently being conducted in the Athabasca Oil Sands area, will continuously measure ambient concentrations of sulphur dioxide and concurrent meteorological data to determine the dry deposition of sulphur dioxide and derive dry deposition velocities.

Contractor: Western Research, Division of Bow Valley Resource Services Ltd.
Funding: $103 620.00

Effects of Deposition of Acid-Forming Substances on Nutrient Cycling and Organic Matter Decomposition in a Forest Ecosystem

The variability of (1) nutrient release from decomposing litter; (2) distribution and leaching characteristics of key nutrients in the litter/soil system; and (3) the uptake of nutrients by mycorrhizal and non-mycorrhizal jackpine seedlings will be studied in two jackpine forest stands. The study will also investigate organic matter transformation in the litter layer. Sampling of litter fall, decomposition rates, biological activity, and total microbial biomass will be done. Major reactions in carbon (energy) flow are to be measured and correlated with the impact of acid-forming substances.

Contractor: D. Parkinson, Kananaskis Centre for Environmental Research, University of Calgary
Funding: $49 962.00

Impacts of Air Pollutant Mixtures on Forest Vegetation and Soils

The study is designed to use both laboratory and field investigations to identify and quantify forest tree responses to single and multiple exposures of acid-forming pollutants. For the Athabasca Oil Sands area, a predictive capability for changes in forest soils and vegetation will be

developed. Both current and future rates of pollution deposition are being considered.

Annual reports are available from the Research Management Division.

Contractor: Canadian Forestry Service

Funding: $40 000.00

The Response of Vegetation Communities to Aerial Emissions

This project will determine structural dynamics in the boreal forest in order to compare any natural changes to those induced by aerial emissions. Results from this project will be used, in conjunction with findings from other studies, to develop sensitive and predictive indicators of the effects of aerial emissions on forest ecosystems (as an early warning). This study will involve process-related phenomena and will establish the relationship between changes occurring in these processes and the structure and function of terrestrial ecosystem. This project has been integrated with other terrestrial studies.

Annual reports are available from the Research Management Division.

Contractor: G. LaRoi, University of Alberta

Funding: $67 600.00

Atmosphere-Biosphere Interface: Application of a Numerical Model to Assess Growth Response of Jackpine to Chronic Atmospheric SO_2 Exposures

Plant response to chronic pollutant exposure is of primary importance in any investigation of natural ecosystems. A multivariate non-linear regression model has been developed by Dr. Nosal to explain the relationship between the growth response of soybean and annual basal area increment of lodgepole pine to ambient chronic atmospheric sulphur dioxide (SO_2) exposures. The main objective of this project is to apply the model to the historical (modelled) air quality data base in the AOSERP area to assess the response of annual radial increment of jackpine to chronic atmospheric SO_2 exposure. The project will be continued in 1985/86.

Contractor: Dr. Nosal, Statscon Statistical Consulting Co.

Funding: $22 500.00 ($12 500.00 in 1984/85 and $10 000.00 in 1985/86)

Atmosphere-Biosphere Interface: Verification of the Model to Determine the Frequency Distribution of SO_2 Ground Level Concentrations

A climatological air quality dispersion model was developed to generate frequency distributions of ground level concentrations of SO_2. Prior to integrating the modelled air quality data with tree core data to assess the impact of acidifying substances on tree growth, however, it is essential that the model be evaluated. This project will evaluate the applicability of the model for predicting air quality data in the AOSERP study area.

Contractor: Dr. Nosal, Department of Mathematics and Statistics, University of Calgary

Funding: $12 500.00

Development of an Acid Deposition Research Program for Alberta Environment, Research Management Division

The Contractor, in collaboration with research managers of the Research Management Division directly involved with the Acid Deposition Research Program, will develop a research program to address the question "Are there detectable impacts of aerial emissions of acidic or acidifying substances on the forest ecosystem in the AOSERP area?"

Contractor: Dr. R. Kickert

Funding: $3 000.00

PUBLICATIONS

Bottenheim, J.W. 1984. Plume chemistry studies during 1980 in the Athabasca Tar Sands region. Prep. for Alberta Environment, Research Management Division, by Atmospheric Dispersion Division, Atmospheric Environment Service. RMD Report OF-80. 259 pp.

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Cheng, L., D. Rogers, A. Davis, E. Peake, and K.L. Grandia. 1984. Aircraft observations of snowfall from a synthetic crude oil plant plume. Presented at the Fourth Joint Conference on Applications of Air Pollution Meteorology. 1984 October 16-19; Portland, Oregon; 4 pp.

Jamal, A.H., D.S. Chadder, W.A. Murray, and R.D. Brymer. 1985. Dry deposition of sulphur dioxide in the Athabasca Oil Sands area. Prep. for Alberta Environment, Research Management Division, by Promet Environmental Group Ltd. RMD Report OF-87. 37 pp.

Legge, A.H., H.C. Kaufmann, and J.W. Winchester. 1984. Tree-ring analysis by PIXE for a historical record of soil chemistry response to acidic air pollution. Nuclear Instruments and Methods in Physics Research. North-Holland, Amsterdam B3(1984):507-510 .

Nyborg, M., R.W. Parker, S. Takyi, and P. Yeung. 1985. Deposition of sulphur and its influence on soils in the AOSERP study area. Prep. for Alberta Environment, Research Management Division, by Soils Department, University of Alberta. RMD Report L-86. 153 pp.

Ross, M.S. and G.H. LaRoi. 1985. Structural dynamics of boreal forest ecosystems on three habitat types in the Hondo-Lesser Slave Lake area of north central Alberta in 1983. Prep. for Alberta Environment, Research Management Division, by Department of Botany, University of Alberta. RMD Report OF-79. 147 pp.

Rudolph, R.C. and D.S. Davison. 1985. Estimates of roughness length from minisonde profiles in the Athabasca Oil Sands Area. Prep. for Alberta Environment, Research Management Division, by INTERA Technologies Ltd. RMD Report L-87. 42 pp.

ENVIRONMENTAL CONSEQUENCES OF IN SITU EXTRACTION TECHNOLOGY

The research emphasis of the aquatic component of AOSERP during 1984/85 addressed the potential effects on surface and groundwater resources of in situ oil sands extraction and recovery. There were three major areas of investigation:

1. The most extensive research involved a regional assessment of the hydrological and hydrochemical characteristics of the Cold Lake Oil Sands deposit, where a steam injection pilot plant has been operated by Esso Resources for several years and a potential production facility is in the final planning stage.
2. A companion project monitored seismic events in the Cold Lake area. The objective of this project was to provide detailed baseline data to monitor the in situ steam injection process as a potential cause of seismic events.
3. The third area of investigation includes a network of survey benchmarks which are monitored at regular intervals to observe any surface deformation or movement.

The objective of each of these projects is to evaluate the possible environmental hazards and human health risks associated with in situ oil sands recovery processes. The synthesis of the results from these studies will provide the Department with the integrated environmental information necessary for making informed management decisions for the safe environmental development of oil sands resources by in situ extraction and recovery processes.

PROJECTS

A Regional Assessment of Hydrological and Hydrochemical Conditions in the Cold Lake Oil Sands Area

This project has been an integral part of the Department's effort to assess the regional hydrogeology and quality of groundwater resources in the Cold Lake area in order to protect the resources from contamination by industrial activities. Studies to date have resulted in a thorough understanding of the natural steadystate groundwater flow regime.

The regional groundwater flow shows a northeasterly trend, obviously not recognizing provincial borders and entering Saskatchewan. The area of research has been expanded to the south and to adjacent areas of Saskatchewan. Co-ordination and active participation of the Saskatchewan Government departments and agencies is being sought.

In addition, fractioning, heat transfer processes, and contaminant transport phenomena are being studied as they relate to deepwell waste injection. For these studies, a three-dimensional finite element computer model is being utilized which was developed during the earlier phases of this project.

Contractor: Dr. B. Hitchon (Alberta Research Council)
Funding: $100 000.00 (Research Management Division)
$100 000.00 (Alberta Research Council)

Oil Sands In Situ Recovery Process Fluids

The objective of this project was to assess possible environmental hazards and human health risks arising from toxic and carcinogenic substances during recovery of heavy oil by in situ methods. Hazardous constituents of process fluids were chemically identified and biologically tested regarding their toxicity and mutagenicity. The formation of these products was related to production conditions, and possible hazards when compared to conventional and other synthetic fuels.

Contractor: Mr. E. Peake (Kananaskis Centre for Environmental Research)
Funding: $50 000.00 (Research Management Division)

PUBLICATIONS

Hitchon, B. In prep. Hydrology of the Cold Lake study area. Prep. for Research Management Division, Alberta Environment.

Peake, E. and M.A. MacLean. In prep. In situ recovery process fluid. Prep. for Research Management Division, Alberta Environment by Kananaskis Centre for Environmental Research, University of Calgary. 230 pp.

LAND RECLAMATION

Petroleum extraction from oil sands causes several reclamation problems, the most serious being current tailings disposal systems. At the end of its 25-year life cycle, a typical oil sands plant producing 19 900 m^3 (125 000 barrels) per day of synthetic crude oil will require a 22 to 31 km^2 tailings pond. The 360 000 000 m^3 of sludge in the pond will remain liquid indefinitely, and must be impounded behind tailings sand dykes 55 to 100 m high. A cover of grasses, legumes, and shrubs will provide erosion protection. Since tailings sand lacks nutrients and drains excessively rapidly, it must be amended with peat and mineral fines to initiate soil development. Extensive areas of overburden dumps and flat tailings sand must also be reclaimed to various land uses.

Research into the reclamation requirements of oil sands development is aimed at defining techniques whereby a self-sustaining, erosion-free cover can be established on tailings sand dykes, and tailings sand storage, and overburden dumps can be returned to productive forest. The resulting soil and plant community combinations must not only fulfill these land use requirements, but must also sustain themselves without indefinite maintenance.

The regulation of surface disturbances in Alberta is the responsibility of the Land Conservation and Reclamation Council, which oversees reclamation research programs. To assist in technical matters related to the development and administration of research programs, the Council appointed the Reclamation Research Technical Advisory Committee (RRTAC), which consists of eight members representing the departments of Agriculture, Energy and Natural Resources, and Environment, and the Alberta Research Council. The Research Management Division represents Alberta Environment on RRTAC and provides project managers and administrative support for many of the projects of this program.

To pool resources and avoid duplication, RRTAC and the industry's Oil Sands Industry Environmental Association (OSIEA) have initiated a joint Reclamation Research Program for oil sands areas. Research is concentrating on identifying suitable tree and shrub species based on survival and growth, and the best combination of soil reconstruction methods (two mixing depths, three clay levels, three peat levels) for reclaiming tailings sand.

PROJECTS

Myrcorrhizal Development on Severely Disturbed Soils

The study: determined the effects of ectomycorrhizal inoculation on growth of jack pine planted on reconstructed soil; developed techniques for inoculation of ectomycorrhizae and VA mycorrhizae; and assessed mycorrhizal status of tree and shrub seedlings being planted into reconstructed soils (in project below).

Contractor: D. Parkinson, University of Calgary

Funding: $89 237.00 (Land Conservation and Reclamation Council-Heritage Savings Trust Fund)

Oil Sands Tailings Soil Reconstruction

In 1983/84, a joint government-industry reclamation project was initiated to identify methods of reconstructing soils from tailings sand, peat, and clay materials that will support a self-maintaining woody shrub and tree cover. A flat tailings sand experimental site was constructed on the Syncrude Canada Ltd. lease at Fort McMurray.

Fifty-four plots, 22 m wide and 44 m long, were created. Treatments included: (1) three organic carbon levels provided by mixing peat into the tailings sand; (2) three levels of clay provided by mixing fine-textured overburden into the tailings sand; and (3) two mixing depths.

Baseline soil data was collected and nine tree and shrub species were planted in the fall of 1985.

Contractor: H. Martens, Hardy Associates (1978) Ltd.

Funding: $47 000.00 (Land Conservation and Reclamation Council-Heritage Savings Trust Fund)
$47 000.00 (Syncrude Canada Ltd., Suncor Inc., and the Oil Sands Industry Environmental Association)

PUBLICATIONS

Bliss, L.C., ed. 1985. **Long-term prediction of vegetation performance on mined sands.** Interim report 1976 to 1977. Prep. for Alberta Environment, Research Management Division by Department of Botany, University of Alberta. RMD Report OF-81. 272 pp.

Bliss, L.C. and J.M. Mayo. 1985. **An ecophysiological investigation of the jackpine woodland with reference to revegetation of mined sands.** Prep. for Alberta Environment, Research Management Division by L.C. Bliss (Department of Botany, University of Washington) and J.M. Mayo (Department of Botany, University of Alberta). RMD Report OF-83. 124 pp.

Danielson, R.M. 1984. **Ectomycorrhizal associations in jack pine stands in northeastern Alberta.** Canadian Journal of Botany 62(5)932-939.

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Danielson, R.M., S. Visser, and D. Parkinson. 1984. **Production of ectomycorrhizae on container-grown jack pine seedlings.** Canadian Journal of Forestry Research 14(1):33-36.

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Parkinson, D., ed. 1984. **Mycorrhizal studies regarding the reclamation of oil sand tailings: production and outplanting of jack pine seedlings** and amounts of VA- and ectomycorrhizal inoculum stockpiled peat. **Prep. for Alberta Environment, Research Management Division. RMD Report OF-70. 131 pp.**

Parkinson, D., R.M. Danielson, C. Griffiths, S. Visser, and J.C. Zak. 1984. Soil microbiology in land reclamation (2 vols.). **Prep. for the Alberta Land Conservation Council, Reclamation Research Technical Advisory Committee. Edmonton, Alberta. Report RRTAC 84-4. 676 pp.**

Visser, S. 1985. Management of microbial processes in surface mined land **reclamation in Western Canada.** IN Soil reclamation processes: Microbiological analysis and applications 7:203-241. R.L. Tate III and D.A. Klein, eds. New York, New York: Marcel Dekker, Inc. 349 pp.

CUMULATIVE LIST OF AOSERP PUBLICATIONS TITLES

1. AOSERP First Annual Report, 1975
2. Walleye and Goldeye Fisheries Investigation in the Peace-Athabasca Delta - 1975
3. Structure of a Traditional Baseline Data System
4. A Preliminary Vegetation Survey of the AOSERP Study Area
5. The Evaluation of Wastewaters from an Oil Sand Extraction Plant
6. Housing for the North. The Stackwall System Construction Report - Mildred Lake Tank and Pump House
7. A Synopsis of the Physical and Biological Limnology and Fishery Programs within the Alberta Oil Sands Area
8. The Impact of Saline Waters upon Freshwater Biota. A Literature Review and Bibliography
9. A Preliminary Investigation into the Magnitude of Fog Occurrence and Associated Problems in the Oil Sands Area
10. Development of a Research Design Related to Archaeological Studies in the Athabasca Oil Sands Area
11. Life Cycles of Some Common Aquatic Insects of the Athabasca River, Alberta
12. Very High Solution Meteorological Satellite Study of the Oil Sands Weather: A Feasibility Study
13. Plume Dispersion Measurements from an Oil Sands Extraction Plant, March 1976
14. (No report published)
15. A Climatology of Low-Level Air Trajectories in the Alberta Oil Sands Area
16. The Feasibility of a Weather Radar near Fort McMurray, Alberta
17. A Survey of Baseline Levels of Contaminants in Aquatic Biota of the AOSERP Study Area
18. Interim Compilation of Stream Gauging Data to December 1976 for AOSERP
19. Calculations of Annual Averaged Sulphur Dioxide Concentrations at Ground Level in the AOSERP Study Area

20. Characterization of Organic Constituents in Waters and Wastewaters of the Athabasca Oil Sands Mining Area

21. AOSERP Second Annual Report, 1976-77

22. AOSERP Interim Report Covering the Period April 1975 to November 1978

23. Acute Lethality of Mine Depressurization Water to Trout-Perch and Rainbow Trout: Volume I

24. Air System Winter Field Study in the AOSERP Study Area, February 1977

25. Review of Pollutant Transformation Processes Relevant to the Alberta Oil Sands Area

26. Interim Report on an Intensive Study of the Fish Fauna of the Muskeg River Watershed of Northeastern Alberta

27. Meteorology and Air Quality Winter Field Study in the AOSERP Study Area, March 1976

28. Interim Report on a Soils Inventory in the Athabasca Oil Sands Area

29. An Inventory System for Atmospheric Emissions in the AOSERP Study Area

30. Ambient Air Quality in the AOSERP Study Area

31. Ecological Habitat Mapping of the AOSERP Study Area: Phase I

32. AOSERP Third Annual Report, 1977-78

33. Relationships Between Habitats, Forages, and Carrying Capacity of Moose Range in Northern Alberta. Part 1: Moose Preferences for Habitat Strata and Forages

34. Heavy Metals in Bottom Sediments of the Mainstem Athabasca River Upstream of Fort McMurray: Volume I

35. The Effects of Sedimentation on the Aquatic Biota

36. Fall Fisheries Investigations in the Athabasca and Clearwater Rivers Upstream of Fort McMurray: Volume I

37. Community Studies: Fort McMurray, Anzac, and Fort MacKay

38. Techniques for the Control of Small Mammal Damage to Plants: A Review

39. The Climatology of the AOSERP Study Area

40. Mixing Characteristics of the Athabasca River below Fort McMurray - Winter Conditions

41. Acute and Chronic Toxicity of Vanadium to Fish

42. Analysis of Fur Production Records for Registered Traplines in the AOSERP Study Area, 1970-1975

43. A Socio-Economic Evaluation of the Recreational Use of Fish and Wildlife Resources in Alberta, with Particular Reference to the AOSERP Study Area. Volume I: Summary and Conclusions

44. Interim Report on Symptomology and Threshold Levels of Air Pollutant Injury to Vegetation, 1975 to 1978

45. Interim Report on Physiology and Mechanisms of Air-Borne Pollutant Injury to Vegetation, 1975 to 1978

46. Interim Report on Ecological Benchmarking and Biomonitoring for Detection of Air-Borne Pollutant Effects on Vegetation and Soils, 1975 to 1978

47. A Visibility Bias Model for Aerial Surveys of Moose in the AOSERP Study Area

48. Interim Report on a Hydrogeological Investigation of the Muskeg River Basin, Alberta

49. The Ecology of Macrobenthic Invertebrate Communities in Harley Creek, Northeastern Alberta

50. Literature Review on Pollution Deposition Processes

51. Interim Compilation of 1975 Suspended Sediment Data for the AOSERP Study Area

52. Plume Dispersion Measurements from an Oil Sands Extraction Plant, June 1977

53. Baseline States of Organic Constituents in the Athabasca River System Upstream of Fort McMurray

54. A Preliminary Study of Chemical and Microbial Characteristics of the Athabasca River in the Athabasca Oil Sands Area of Northeastern Alberta

55. Microbial Populations in the Athabasca River

56. The Acute Toxicity of Saline Groundwater and of Vanadium to Fish and Aquatic Invertebrates

57. Ecological Habitat Mapping of the AOSERP Study ARea (supplement). Phase 1

58. Interim Report on Ecological Studies on the Lower Trophic Levels of Muskeg Rivers within the AOSERP Study Area

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63. Analysis of AOSERP Plume Sigma Data

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65. A Review and Assessment of the Baseline Data Relevant to the Impacts of Oil Sands Development on Large Bears in the AOSERP Study Area

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